TELECOMMUNICATIONS®

INDUSTRY ASSOCIATION

July 8, 1997

Mr. Dan Phythyon
Acting Chief, Wireless Telecommunications Bureau
Federal Communications Commission
2025 M Street, N.W., Room 5002
Washington, D.C. 20554

DOCKET FILE COPY ORIGINAL

Re: PR Docket No. 92-235

Dear Mr. Phythyon:

Given the current shared nature of the bands subject to refarming, frequency coordinators already deploy a number of tools to assist licensees in selecting the most appropriate frequency. These include both technical criteria and an examination of compatibility among users from a business perspective. These tools have served users and the Commission well; the bands below 512 MHz support approximately 16 million private radio users. Implementation of refarming in these private land mobile bands necessarily creates a more complex environment in which multiple technologies and multiple bandwidths are deployed.

In its Second Report and Order in the refarming proceeding released March 12, 1997, the Commission noted the need for a minimum set of technical coordination procedures all coordinators could use and referenced ongoing efforts of the Telecommunications Industry Association (TIA) in this area. In addition, in its Further Notice of Proposed Rulemaking, the Commission is addressing the issue of whether and how private land mobile users can be offered "protected service areas (PSA's)." Accordingly, frequency coordinators may require new tools to assist users in selecting the most appropriate frequencies among the possible options.

The TIA has developed and approved a report (copy enclosed) defining recommended technical approaches which may assist frequency coordinators in the new refarming environment. The report provides coordinators with recommendations on technical modeling which can be used to help assess potential interference between systems of different bandwidths and/or technologies. The report should be particularly helpful to coordinators in reviewing and assessing requests for PSA's in these shared bands, should the Commission adopt rules providing for PSA's. Combined with other methods coordinators already use to implement sharing in the bands, TIA believes users will benefit from these recommendations. TIA is also taking the necessary steps to ballot and publicize the report as a "Telecommunications Systems Bulletin" so it will be widely available.

This report has already been provided to the frequency coordinators, some of which are already working with software developers to finalize and test computer programs and subroutines based on the modeling and simulation techniques embodied in the TIA recommendations. TIA applauds these efforts, as such software programs and subroutines are necessary to incorporate these recommendations into a cost-effective and efficient frequency coordination process by the effective date of the Commission's Second Report and Order, October 17, 1997.

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Representing the telecommunications industry in
association with the Electronic Industries Association

Given the close cooperation necessary between the Commission and the industry to move remaining refarming issues to an expeditious conclusion, TIA is submitting this document for information purposes. TIA views this report as a valuable and necessary contribution to the refarming effort. However, we believe it would be inappropriate for the Commission to require use of these TIA recommendations by rule. Software tools and their underlying modeling and simulation techniques are routinely modified and improved through the experience of testing and implementation. Therefore, incorporation of the report into the rules could inadvertently hamper implementation of TIA's recommendations and coordinators' associated software tools.

Should you have any questions concerning this submission, please do not hesitate to contact me at (847) 576-3327 or Stuart Overby at (202) 371-6940.

Sincerely,

Wayne Leland
Chair, TIA Private Radio Section
Mobile and Personal Communications Division

Enclosure

cc: David Horowitz
        Chief, Private Wireless Division

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TELECOMMUNICATIONS INDUSTRY ASSOCIATION

A REPORT ON
TECHNOLOGY INDEPENDENT METHODOLOGY
FOR THE
MODELING, SIMULATION AND EMPIRICAL VERIFICATION
OF WIRELESS COMMUNICATIONS SYSTEM PERFORMANCE
IN NOISE AND INTERFERENCE LIMITED SYSTEMS
OPERATING ON FREQUENCIES BETWEEN 30 AND 1500 MHz

Prepared By:

TIA TR8 Working Group 8.8
Technology Compatibility

For:

TR-8 Mobile and Personal Private Radio Standards Committee
TIA Mobile and Personal Communications

In Conjunction with the:

Institute of Electrical and Electronics Engineers
Vehicular Technology Society
Propagation Committee

20 May 1997

Document Revision History

13 September 1994
First Draft prepared by Olson

30 September 1994
Changed Availability to Reliability to avoid confusion with equipment reliability. Changed Grade of Service references to Channel Performance Criterion.

25 January 1995
Typographic corrections, added Confidence Interval and changed the wavelength requirements to differentiate power measurements from BER measurements.

25 March 1995
Incorporated requested changes and expanded Adjacent Channel information.

5 June 1995
Incorporated Adjacent Channel Interference Test Methodology from Hiben

8 August 1995
Incorporated Anderson's section's on Shadowing (4.2), Terrain Elevation Databases (4.3), Local Clutter or Ground Cover (4.4) and a 3D Extension to the propagation model for prediction multipath time dispersion (delay spread) (4.5), Incorporated equipment delay spread measurement methodology from Hiben (4.7), Incorporated Ambient Noise Methodology from Rubinstein (5.0-5.2), Incorporated Symbolic Noise Methodology from Olson, Document edited by Stone

8 September 1995
Document edited and Forward (1.0) added by Stone; Incorporated Adjacent Channel Power Ratio Measurement Methodology from Wieczorek; Incorporated 4.2.1.1 Sample OKUMURA/HATA/DAVIDSON Program-Metric from Davidson; Updated 4.1.2.2 Sample OKUMURA/HATA/DAVIDSON Program-English, from Davidson; Incorporated Relative Advantages of Tiled vs. Radial Metaphors from Rubinstein (4.8). Overview merged into Introduction and Scope (2.0)

13 November 1995
Document edited, spell checked, and reformatted by Stone; Appendix-A Recommended Data Elements (Placeholder) from Stone

12 December 1995
Document reedited by Stone; Title change by Stone to reflect 30-1500 MHz Application Data from 8 Sept. 1995 version mistakenly deleted was replaced
Appendix-A, populated with material from Anderson, Hiben, Olson and Rubinstein, data elements

Document Revision History (Continued)

12 December 1995 (Continued)
Appendix-B from Anderson, Olson, and Rubinstein added
Appendix-C from Stone added
Section 1.0 revised by Stone

16 January 1996
Document re-edited by Stone to include previous Olson comments; Sections missing in V.12 but included in V.10/11 re-inserted; Section 6.1.6.2 changed to reflect analog FM ACPR; DAQ-2 and DAQ-3 redefined; References to Linear Modulations added throughout document; Section 6.1.6.3 added from Wieczorek to address C4FM and QPSK-C ACPR; Sections 6.1.7.2 through 6.1.7.17 added as place holders for delay spread data for many different modulations; Appendix-B rewritten by Rubinstein; Appendix-C modified by Stone to delete reference to public service

26 February 1996
Document re-edited by Stone to include revised Table 5 from Olson; All tables moved to newly created Appendix-A; Previous Appendices A, B, C renamed B, C, D; Additions to new Appendix-C (old Appendix-B) from Anderson added; All references to CM changed to DAQ; All references to Criterion Channel Performance (CCP) changed to Channel Performance Criterion (CPC); Sections on Protected Service Area (PSA) and Delivered Audio Quality (DAQ) from Olson incorporated; Incorrect Figure 1 replaced with correct figure

4 March 1996
Document re-edited by Stone to include comments from Olson and Rubinstein.

19 March 1996
All sections "6.1.X" renumbered as "6.X" with Sections 6.1 through 6.5.4 (new numbering system) replaced with new text. Section 5.8 rewritten. Tables 3, 8, and 9 consolidated into a single table, Table 3. Tables 8 and 9 deleted. New Table 4 inserted with Filter Formulas. Table 5 updated to be consistent with the other tables. Old Table 4 and 6 deleted because information is contained in Table 5. Old Table 10 (New Table 8) reworked for clarity. New Appendix-E added by Rubinstein. Figures 11 and 12 replaced with improved figures.

5 April 1996
Tables 3 and 4 replaced with updated tables. Title changed and Title Page changed to include "For: TR-8 Mobile and Personal Private Radio Standards Committee, TIA Mobile and Personal Communications" as directed by TR8. Comments incorporated as directed by TR8: the word "standard", where it was used in the normative sense, was replaced with the word "report". Acknowledgments page updated. Acronyms and definitions updated. Sections 3.6.2 and 3.6.3 revised by Hiben. Sections 6.6 through 6.6.4 revised by Olson. Tables C-3 through C-9 added by Olson. Table 3, for RZ SSB, the IF Filter Type entry and

bandwidth were changed to "TBD"; and abbreviation for RZ SSB corrected per Crowley. Old Tables 18-20 deleted by Olson.

22 April 1996
Equations 1, 2, 17, 18, 20, and 22 corrected by Olson and Rubinstein. Tables 3, 5, and 7 corrected by Olson. Section 6.6 and all subsections rewritten by Wieczorek. Figure 7 updated by Olson. Tables C-1 and C-2 corrected by Olson. Bibliography updated by Rubinstein. Global search performed to change Km and kM to km. Document edited by Olson.

29 April 1996
Document edited by Olson.

10 December 1996
Version 17. Document edited by Stone to reflect Version 17 applicability to analog and digital voice only. Preface added by Stone. Equation 2 moved to follow directly after Equation 1 by Olson and Rubinstein. Equation 36 was replaced with new equation 36 with correct square within the radical. Section 5.2 was renumbered 5.2.3 and renamed by Olson and Rubinstein. New sections 5.2, 5.2.1, and 5.2.2 were added by Olson and Rubinstein. A paragraph was added at the end of section 5.8 by Olson and Rubinstein. Section 6.6.1, first paragraph, last sentence, phrasing was changed by Olson and Rubinstein. The titles of sections 6.6.1.1 and 6.6.1.2 were changed by Olson and Rubinstein. Table 2, 1/2 and 1/4 were changed to $\lambda/2$ and $\lambda/4$ by Olson and Rubinstein. Table 5 was updated by Olson and Rubinstein. The cross-references in Table 7 were changed to 6.6.6.2 by Olson and Rubinstein. A footnote was added to Table 12 by Olson and Rubinstein. The flow charts in Appendix-C were replaced with new text by Olson and Rubinstein. Table C-10 was added by Olson and Rubinstein. Section E-10 was added to Appendix-E by Olson and Rubinstein.

20 December 1996
Rubinstein added updates and corrections to the Okumura/Hata/Davidson Model in Sections 5.1.2, 5.1.2.1, and 5.1.2.2.

6 January 1997
Version 17 revised. New Section 3.4.3 added by Arcuri. Wording in Section 5.8 modified by Stone. Tables 1, 3, 5, and 7 modified by Ericsson to include $\pi/4$ DQPSK (IMBE) TDMA (12.5 kHz), EDACS® (IMBE) (25 kHz), and EDACS® (IMBE) (12.5 kHz). Table 5 modified by Olson to include VSELP.

7 April 1997
Version 18 created. Shively, SEA, added clarifications and corrections from document numbered WG8.8/97-03-073, item number 3 (first part only) to page 11, Section 3.5.1; item number 5 to page 21, Section 4.4.2; item number 6 (first part as is; second part with different wording) to page 24, Section 4.4.3; item number 7 (with revised wording) to page 25, Section 4.4.3; and item number 8 to page 26, Section 4.4.3. Rubinstein modified Section 5.9 and Appendix-C from document numbers WG8.8-97-03-074 and WG8.8-97-03-075. A new Section 5.9 and 5.91 was added. Sections C.7.3.2 through C.7.3.2.6 were renumbered to be Sections 5.9.2 through 5.9.2.6 and moved to the body of the main document immediately following the new Sections 5.9 and 5.9.1. Sections C.7.3.1 and C.7.4 were deleted. New text was added after C.7.3. Rubinstein modified Sections 5.1.2.1 and 5.1.2.2 based upon document numbers WG8.8-97-03-076 and WG8.8-97-03-077. Section 5.1.2.1, Sample OKUMURA/HATA/DAVIDSON Program - Metric, and Section 5.1.2.2, Sample OKUMURA/HATA/DAVIDSON Program - English were changed to reflect the use of 300 MHz, and changes in the urban environment. Rubinstein modified Section 5.6 based upon document number WG8.8-97-03-078, which added paths for use to verify models. Olson provided modifications and corrections based upon document number WG8.8-97-03-080. The title of Section 3.4.3 was changed to "Tile Reliability" and the body of text to this section was modified. Tile Reliability was added to the Definitions. The equation on Page 5 that was not numbered was numbered Eq. 5, and all succeeding equations and references thereto was amended to reflect this addition. Effective Noise Bandwidth was changed to Equivalent Noise Bandwidth throughout the document, including the Definitions and Abbreviations. The abbreviation ENBW was substituted for subsequent occurrences of the phrase. Section 3.5.1 was modified to include clarifications. Figure 2 was modified to make it more legible. The last two paragraphs in Section 3.6.1 was updated based on newer data. Section 4.4.2, C/N was changed to C_s/N. Section 6.0 was modified for clarity. Section 6.2.1, the limits for Eq. 33 were changed, and the reference to Table 13 was clarified. Section 6.4.3 was modified to include the use of triangles and hexagons. The letters pi were replaced with π. The Definitions and Abbreviations were updated to include Spectral Power Density.

28 April 1997
Figures 2, 3, and 4 were modified to fit on the page (no content was changed). Section 5.3 was modified to reflect the FCC filing requirements of 2-10 miles (3-16 km). Rubinstein added reference [20] Hufford, to Section 8.0, and included references to Hufford in 5.6. Rubinstein modified the definition of HAAT in 7.1. Section 7.2 was modified to include EDACS®, change dBu to dBµ, and correct ITU-R and ITU-T. Stone clarified the use of mean power value in 6.8.1, 6.8.4, and 6.8.5. Rubinstein and Olson modified Appendix-E to add new E.3 and E.4. New Sections 3.4.3 and 3.4.4 added by Olson, along with definitions in Section 7.1 for Tile Reliability and Tile Reliability Margin.

20 May 1997

- Version 20 created. Sections 3.6.2.3.1 and 3.6.2.3.2 replaced with revised Sections by Olson. Section 3.6.2.3.3 deleted by Olson, and Section 3.6.2.3.4 renumbered as 3.6.2.3.3. Sections 6.0, 6.2, 6.3.2, 6.4.3, 6.5.3, 6.5.4, and 6.8.1 rewritten and revised by Hofmeister. Bullets in Section 6.8.2 indented by Hofmeister. Section 5.0, 5.2, 5.2.1, 5.2.2, 5.2.2.1, 5.2.2.2, 5.2.2.3, 5.2.3, 5.2.3.1, 5.2.3.2, and 5.2.3.3 rewritten/added by Anderson. Equations 27 through 39 renumbered as Equations 46 through 58 due to the additional equations added by Anderson in Section 5.0 and subsections thereof. All occurrences of EDACS throughout the document annotated with ®. Errata sheet for Sections 5.3.1, 5.3.1.1, and 5.3.1.2 from Rubinstein for Version 19 incorporated into main body of document. An introductory sentence to Appendix-E was added by Olson on Page 2 preceeding Section 2.0. Olson modified Section 3.4.2, last sentence, to include "at a minimum". Figure 2 was replaced with a new Figure 2 by Olson - no changes were made, the graphics of the figure were upgraded. The bullets on pages 9-10 were re-ordered and modified by Olson. All occurrences of IIP^3, OIP^3, and IP^3 were changed to IIP^3, OIP^3, and IP^3. Section 5.2, fourth paragraph, first sentence was replaced by Ericsson. Section 5.2.2, second paragraph, was corrected by Rubinstein to reflect 8,451,000 metes. Section 5.2.2.1, second to last paragraph, "angles of incident" was changed to "angles of incidence" by Olson. The path numbers in Section 5.6 were modified by Olson to delete one incorrect number and delete one redundant number. Section 5.9.2.2 "mean = O" was changed to "mean = 0". Section 6.0, fourth paragraph, third sentence was deleted as agreed to by Working Group in Phoenix. Section 6.3.2, last sentence was deleted as agreed to by Working Group in Phoenix. Section 6.8.1, last sentence, the word "approximately" was inserted preceding 2 dB by Olson. Section 6.8.3, last paragraph, last sentence, the words "simulated test" were inserted by Olson preceding "reference sensitivity". Table B-3, the last sentence in the text following the paragraph was deleted by Olson and Stone. Section C.5 was modified by Olson to replace "OHD" in C.5.1 with "propagation". Section C.5.2 was deleted, and the subsequent subsections renumbered by Olson. Section C.5.3, L_3 was changed by Olson to L_2. Section C.5.4 was changed by Olson to delete L_3, and the values of the equation changed to "136 + " to reflect this. Section C.6.4.3 was modified by Olson to include a complete square root sign in the equation.

ACKNOWLEDGMENTS

It is believed that this document represents a watershed event in the wireless communications arena. For the first time a quantitative and systematic approach to addressing the challenges posed by technology evolution in a wireless communications environment is presented.

While this work is indeed the product of many individuals technical contributions, the genesis of the document is the brainchild of Mr. Carl B. "Bernie" Olson. Mr. Olson's formative contributions are therefore rightly noted. In addition, substantive contributions have been made by: Dr. Harry Anderson of EDX Engineering; Mr. Dominic Arcuri of Ericsson; Mr. John Oblak of the E.F. Johnson Company; Mr. Brad Hiben of Motorola; Mr. Tom Rubinstein of Motorola; Mr. Casey Hill of Motorola; Mr. Al Wieczorek of Motorola; and Ms. Judith F. Furie of INS/CECOM.

A special acknowledgment is made to the United States Immigration and Naturalization Service, and in particular to Mr. David G. Butler, Chief of the Headquarters Radio System Section, for providing staff and resources that were instrumental in the formulation, editing, and production of this document.

Mr. David Brown
Dr. Gregory M. Stone
Co-Chairmen, WG 8.8

Washington, D.C.
May 1997

PREFACE

This Version 20 release is intended to support the engineering, design, and spectrum management of wireless systems operating between 30 and 1500 MHz employing analog and digital voice or integrated digital voice and data teleservices.

Version 20 is not intended for use with packet or circuit switched data only teleservices.

A future release will incorporate those parameters and procedures applicable to packet and circuit switched data only teleservices.

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1.0   TIA TR8 WG8.8 Technology Compatibility Committee Charter and Mission

TIA's Land Mobile Radio Section TR8 WG 8.8 Technology Compatibility Committee is working under a charter and mission statement to address the following technical challenges:

- Accommodating the insertion of bandwidth efficient narrowband technologies likely to be deployed as a result of the Commissions "Spectrum Refarming" efforts;

- Assessing and quantifying the impact of new narrowband/bandwidth efficient digital and analog technologies on existing analog and digital technologies;

- Assessing and quantifying the impact of existing analog and digital technologies on new narrowband/bandwidth efficient digital and analog technologies; and

- Addressing migration and spectrum management issues involved in the transition to narrowband/bandwidth efficient digital and analog technologies. This will include developing solutions to the spectrum management and frequency coordination issues resulting from the narrowbanding of existing spectrum considering: channel spacing from 30 and 25 kHz to 15, 12.5, 7.5, 6.25, and 5 kHz.

To accomplish these objectives, the WG8.8 Committee has joined forces with the Institute of Electrical and Electronic Engineers (IEEE) Vehicular Technology Society's (VTS) Propagation Committee. The IEEE Propagation Committee's contribution to this technology compatibility effort is in the area of supporting development and adoption of standard two dimensional (2D) and three dimensional (3D) electromagnetic wave propagation models, a diffraction model, and reports relating to the selection of terrain and land use data bases. This propagation related effort will be generalizable to the electromagnetic wave propagation modeling and simulation of both current and future land mobile wireless systems.

1.1   Responsiveness to User Requirements

The Committee also has been particularly responsive to specific requests from two particular user organizations: the Association of Public Safety Communications Officials, International (APCO) and the Land Mobile Communications Council (LMCC).

On the 21st of July 1995, APCO Automated Frequency Coordination Inc., requested technical assistance from the Committee in facilitating the accommodation of advanced technologies in a post refarming environment. APCO, among others, specifically requested that the Committee establish a standardized methodology for the modeling and simulation

of narrowband/bandwidth efficient technologies operating in a post "refarming" environment as applicable to Spectrum Management. Subsequently, on 20 November 1995, the LMCC requested the Committee's efforts be expanded to address recommendations for a "Licensee Data Set" and for a methodology to determine "Service Areas" for existing licensees.

In response to these requests of the user community, a substantive evolution of this Committee work product has occurred. For example, Appendix-B to this document contains a recommended set of data elements for automated modeling, simulation, and spectrum management of wireless communications systems. This technical appendix addresses one of the LMCC requirements for a "Data Set" for post refarming spectrum management.

Likewise, Appendix-C serves to provide a hypothetical information flow in a simplified explanation of the spectrum management/frequency coordination process employing the specific reports and recommendations contained herein.

Appendix-D contains a methodology for establishing service areas for existing licenses, in response to LMCC's request.

Appendix-E contains a work sheet for selecting various optional user choices.

2.0 Document Introduction & Scope

In satisfaction of TIA's commitment to the spectrum refarming effort and in response to a request from APCO Automated Frequency Coordination, Inc., for post refarming technical support, the Compatibility Committee's effort has focused on the following:

- Establishment of standardized methodology for modeling and simulating narrowband/bandwidth efficient technologies operating in a post "Refarming" environment;

- Establishment of a standardized methodology for empirically confirming the performance of narrowband/bandwidth efficient systems operating in a post "Refarming" environment; and

- Aggregating the modeling, simulation and empirical performance verification reports into a unified "Spectrum Management Tool Kit" which may be employed by frequency coordinators, systems engineers and system operators.

This document entitled, "A Report on Technology Independent Methodology for the Modeling, Simulation, and Empirical Verification of Wireless Communications System Performance in Noise and Interference Limited Systems Operating On Frequencies Between 30 And 1500 MHz," serves as a report to define the compatibility criteria of the

various different modulation types using terms consistent with overall TIA, IEEE, and ITU land mobile efforts.

The expressed purpose of this Committee document is to define and advance a scientifically sound standardized methodology for addressing technology compatibility. This document provides a formal structure and quantitative technical parameters from which automated design and spectrum management tools can be developed based on proposed configurations that may temporarily exist during a migration process or for longer term solutions for systems that have different technologies.

As wireless communications systems evolve, the complexity in determining compatibility between different types of modulation, different operational geographic areas, and application usage increases.

Spectrum managers, system designers and system maintainers have a common interest in utilizing the most accurate and repeatable modeling and simulation capabilities to determine likely wireless communication system performance. With increasing market competition both in terms of modulation techniques offered and in the number of entities involved in wireless communications systems a standardized approach and methodology is needed in the modeling and simulation of wireless communications system performance considering both analog and digital practices at all frequency bands of interest.

In addition, subsequent to wireless communications system implementation, validity or acceptance testing is often an issue subject to much debate and uncertainty. Long after a system is in place and optimized, future interference dispute resolution demands application of a unified quantitative methodology for assessing system performance and interference.

This document also provides a standardized definition and methodology to a process for determining when various wireless communications configurations are compatible. The document contains performance recommendations for public safety and non-public safety type systems that should be used in the modeling and simulation of these systems. This document also satisfies the requirement for a standardized empirical measurement methodology that will be useful for routine proof-of-performance and acceptance testing and in dispute resolution of interference cases that are likely to emerge in the future.

To provide this utility requires that various performance criteria be defined for the different modulations and their specific implementations by specific manufacturers. Furthermore, sufficient reference information will be provided so that software applications can developed and employed to determine if the desired system performance can be realized.

Wireless system performance will be modeled and simulated with the effects of single or multiple potential distortion sources taken into account. These sources include:

- Co-channel users
- Adjacent channel users
- Internal noise sources
- External noise sources
- Equipment non-linearities
- Transmission path geometry
- Delay spread and differential signal phase

Predictions of system performance will be based on the desired RF carrier verses the combined effects of single or multiple performance degrading sources. Performance will be based on a faded environment to more accurately simulate actual usage and will consider both signal magnitude and phase attributes.

It is anticipated that this document will serve as the standard reference for developers and suppliers of wireless communications system design, modeling, simulation and spectrum management software and automated tools.

As the concepts, parameters and methodologies advanced here represent the collective work product of thousands of successful systems worldwide, it is envisioned that future wireless systems that employ this report in the design , modeling, simulation and implementation processes will benefit from consistent performance as designed. Furthermore, spectrum management based upon the same precepts and standard will not only be "consistent" with the designs submitted, but will be more accurate and more flexible accommodating each unique set of conditions rather than relying upon generalized tables and "rules-of-thumb".

Since the migration from the analog world of today to the digital future will be gradual, we anticipate additions to the collective knowledge base. Therefore, on a regular basis, initially on an annual basis, this document will be revised based upon the receipt of relevant additions and/or corrections. Updates will also be issued that reflect refinements as requested by the body of systems designers, and spectrum managers who will ultimately be the users of this report.

3.0   Wireless System Technical Performance Definition and Criteria

The complete definition of the user requirements eventually evolves into the set of conformance requirements. Based on a knowledge of what the User Requirements are and how the conformance testing will be conducted, iterative predictions can be made to arrive at a final design. The following factors should be defined before this process can be accomplished.

3.1   Service Area

This is the users operational area within which a radio system should:

- Provide the specified Channel Performance in the defined area

- Provide the specified CPC Reliability in the defined area

The Service Area Reliability is the computed average of all the individual reliabilities calculated at the data base locations as predicted by the propagation model. These locations shall be uniformly distributed across the Service Area. The Service Area shall be defined in geographic terms.

3.2 Channel Performance Criterion (CPC)

The CPC is the specified minimum design performance level in a faded channel. Its value will be dependent upon ratios of the desired signal to that of the other distortion mechanisms which exist within the service area. It will be defined as a minimum Rayleigh faded carrier magnitude to the sum of all the appropriate static or faded distortion sources, $C_f/(\Sigma I+\Sigma N)$. This Faded Reference Sensitivity will require an absolute power reference, and for digital systems an absolute value in terms of a delay spread performance factor which addresses the decrease in sensitivity which occurs at some given delay spread parameter, after which critical delay spread is achieved. This is provided via the Reference Sensitivity, a static desired carrier-to-noise ratio, C_s/N, for bench testing which provides the absolute power requirement for the C_s/N criterion, for example, 5% static BER at 55 μs delay spread for a given digital modulation or 12 dB SINAD for analog frequency modulation. The delay spread test is with standard input signal level. Table 5 of Appendix-A contains a tabulation of common modulations for projected CPCs.

The Faded Reference Sensitivity may be for a lower CPC than specified by the User. The appropriate design faded sensitivity for the required CPC shall be used. It will be based on the required $C_f/(\Sigma I+\Sigma N)$ for the signal quality baseline required for the particular radio service.

3.3 CPC Reliability

Reliability is the probability that the required CPC will exist at a specified location. It is computed by predicting the mean signal level at a point and determining the margin between the mean and the prediction. The magnitude of this margin determines the probability of achieving the signal level required to produce the CPC.

3.4 CPC Reliability Design Targets

The reliability of wireless communications over a prescribed area is often a issue that is misunderstood. Standardized definitions that are universally applicable are necessary and are presented in the following:

3.4.1 Contour Reliability

The concept of Contour Reliability is a method of specifying both a minimum CPC and a minimum probability of achieving that requirement. The locus of points that meet these criteria would form a contour. Ideally that contour would follow the boundaries of the User's Service Area.

A regulatory contour reliability represents a specific case where the prediction model uses a single "height above the average terrain" value along each radio propagation path, radial between the site and a predicted point, such that predicted signal levels will only decrease with increased distance from the site. This is unrealistic but useful in administration of frequency reuse as it eliminates the randomness of predicted signal levels due to terrain variations, producing a "single unambiguous predicted location" along each radial that provides the specified field strength. The contour is then the locus of those points. Note that the signal strength may denote some specific CPC, but not necessarily. Historically, reuse coordination is based on a non overlapping of contours. The existing systems desired (C) signal contour at some reliability, typically 50%, cannot be overlapped by the proposed new co-channel carrier (I) at a specific reliability, typically 10%.

A formula for converting contour reliability into area reliability from Reudink [1], page 127 is:

$$F_u = \frac{1}{2} \bullet \left(1 + erf(a) + \exp\left(\frac{2 \bullet a \bullet b + 1}{b^2}\right) \bullet \left(1 - erf \frac{(a \bullet b + 1)}{b}\right)\right) \qquad \text{[Eq. 1]}$$

At the contour,

$$Px_0 = \frac{1}{2}\left(erfc(a)\right) \qquad \text{[Eq. 2]}$$

where

$$a = \frac{x_o - \alpha}{\sigma \bullet \sqrt{2}} = \frac{Z}{\sqrt{2}}$$

$$b = 10 \bullet n \bullet \left(\frac{\log_{10} e}{\sigma \bullet \sqrt{2}}\right)$$

and,

α is a constant
x_o is the threshold
σ is the log normal standard deviation
n is the power loss value for r^{-n}
F_u is the fractional useful service area probability
Px_o is the fractional probability of x_o at the contour
Z is the standard deviate unit for the fractional reliability at the contour

The resultant solution is based on a uniform power loss exponent and a homogenous environmental loss (smooth earth). Although it doesn't include the effects of terrain, it provides a reasonable first order estimate.

3.4.2 CPC Service Area Reliability

Since contour reliability is a frequently specified user requirement, its conversion to Area reliability is very important as confirmation testing (Section 6.0) is based on the Area reliability, *not* on the contour reliability. Note however that the area being defined is that of a bounding contour, not of an irregular Service Area. The design process will produce an area reliability where, at a minimum, the contour reliability is provided throughout the service area.

Figure 1 shows a conversion chart between contour reliability and Area reliability for a constant power loss exponent of 3.5, and three different values of σ.
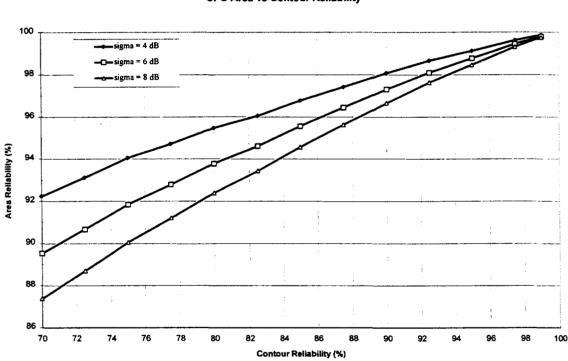
Figure 1
CPC Area vs Contour Reliability

Figure 1. CPC Area vs. Contour Reliability

This seemingly confusing criterion results from two different definitions for Contour reliability. The regulatory definition is not useful in designing a system as the contours do not actually exist. They were developed as an aid for frequency reuse coordination. The definition used in this document is to develop a design target for predicting a CPC.

3.4.3 Tile Reliability Margin

The margin, in dB, provided to create a minimum acceptable probability of achieving the required CPC. This margin is used to determine whether a specific tile will be considered as being a pass or fail, which is used in the calculation of the CPC Area Reliability. This

tile reliability margin will be less than the Area Reliability. For example, if the minimum acceptable probability for a tile is 90% probability of achieving the CPC target value, the tile reliability margin, from Section 5.8, would be 8.2 dB. This would produce a CPC Area Reliability, from Figure 1, of approximately 97.5%. The exact value would be subject to an actual prediction rather than the use of the simple model of Figure 1.

3.4.4   Tile Reliability

CPC Area Reliability requires that within a user specified percentage of tiles (sectors) bounded by the service area, the predicted mean signal must exceed the CPC design target by an amount equal to or greater than the Tile Reliability Margin. Thus, the predicted mean signal within each tile includes a tile reliability margin, over and above the specified CPC threshold signal level, to predict that specific level of performance. Any location that has a predicted signal level producing a tile reliability margin less than specified is treated as failing, and is represented on the map accordingly.

The number of tiles which contain a tile margin equal to or greater than that specified above the CPC requirement, divided by the total numbers of tiles, directly predicts the CPC Area Reliability.

3.5   Margins for CPC

Different CPCs, such as those for digital data, may require additional margins above the "standard faded sensitivity". These margins should be used to increase the predicted signal levels and to compensate for the aggregated delay spread so as to achieve the appropriate $C/(\Sigma I+\Sigma N)$ required to provide the CPC.

3.5.1   CPC Subjective Criterion

SINAD equivalent intelligibility, Mean Opinion Scores (MOS) and Circuit Merit have been frequently used to define a Channel Performance Criterion (CPC). A new term, Delivered Audio Quality (DAQ), was developed to facilitate mapping of analog and digital system performance to Circuit Merit and SINAD equivalent intelligibility. DAQ and its SINAD equivalent intelligibility define a subjective evaluation using understandability, minimizing repetition and degradation due to noise to establish high scores. For the purposes of this report, DAQ values are defined in terms of SINAD equivalent intelligibility. These are shown in Table 1 in Appendix-A. Table 1 sets out the approximate equivalency between DAQ and SINAD. Recommendations for public safety, and non-public safety, are provided in Section 3.6.2.2 that follows and D.2.10. In digital systems, the noise factor is greatly diminished and the understandability becomes the predominant factor. The final conversion is what will be defined as the CPC.

The goal of DAQ is to determine what mean $C/(I+N)$ is required to produce a subjective audio quality metric under Rayleigh multipath fading. The reference is to FM analog radio SINAD equivalent intelligibility. That is a static analog measurement so the Table 1 description has been provided to provide a cross-reference.

The requirement for 20 dBS equivalency produces a DAQ of approximately 3.4. This value can then be used for linear interpolation of the existing criteria. CPC requirements would normally specify either a 3 or 3.4 DAQ at the boundary of a protected service area. Note that regulatory limitations may preclude providing this level of CPC for portable in-building coverage.

Noise/Distortion is intended to represent Analog/Digital configurations, where Noise is the predominant factor for degrading Analog DAQ, while Distortion and vocoder artifacts represent the predominant factor for degrading Digital DAQ. Repetition represents the requirement due to low intelligibility.

These values are subjective and will have variability amongst individuals as well as configurations of equipment and distractions such as background noise. They are intended to represent the mean opinion scores of a group of individuals, thus providing a goal for evaluation. It is recommended that samples of each criterion be provided to calibrate user expectations.

Figure 2 shows the various factors that must be included to make a prediction for a specific CPC.

- The Thermal Noise Threshold is the noise contribution of the receiver due to thermal noise. It can be calculated using Boltzmann's constant and an assumed room temperature of 290°K, correcting for the receiver's Equivalent Noise Bandwidth (ENBW) and Noise Figure. This is:

Thermal Noise Threshold (dBm) = -174 dBm + 10 log (ENBW) + NF $_{dB}$ [Eq. 3]

Where ENBW is in Hz.

This then defines the Noise used in all subsequent tests.

- The Static Threshold is the Reference Sensitivity of the receiver. It shall have a static carrier to noise (C_s/N) value for a static performance test, relative to the Thermal Noise Threshold and can be expressed as an absolute power level in dBm or μV's across 50Ω.

- The Faded Threshold differs slightly in definition from the Faded Reference Sensitivity as it is for a faded performance criterion. In the specific case of C4FM, the Faded Reference Sensitivity is for the standard BER (5%) per clause 2.1.5.1 of TIA TSB102.CAAA. The Faded Threshold is for a BER that provides for the specific design CPC. A faded carrier to noise (C_f/N) value must be available for this performance level. This C_f/N value will be evaluated as being a $C_f/(\Sigma I + \Sigma N)$.

ERP

Propagation Model Loss

Includes Environmental

Design Target

Reliability & Confidence

ATP Target

3 dB | Quarterwave to dipole
and cable losses

Acceptance P/F

Usage Adjustment
Building/Auto Loss Factor

Antenna Adjustment(s)

Portable Antenna Factor On Street

Body/Pattern/Polarization

Relative to half wave dipole

Faded Performance Threshold

Faded Performance Margin
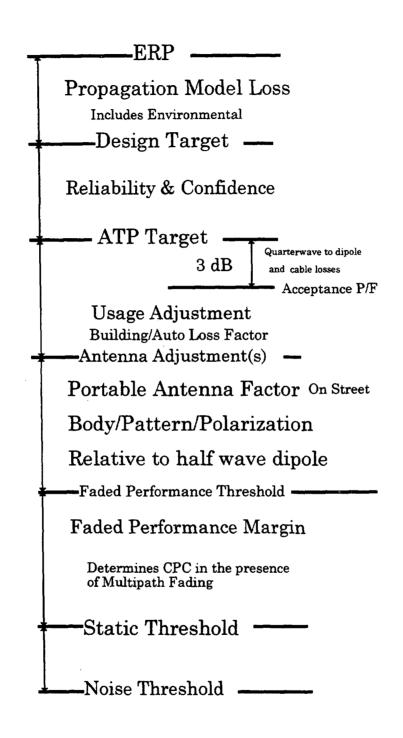
Determines CPC in the presence
of Multipath Fading

Static Threshold

Noise Threshold

Figure 2. Prediction Factors